United States Environmental Protection Agency
Office of Solid Waste and Emergency Response (5102G)
EPA 542-F-96-014
September 1996

A Citizen's Guide to Phytoremediation

Technology Innovation Office
Technology Fact Sheet

What is phytoremediation?

Phytoremediation is the use of plants and trees to clean up contaminated soil and water. Growing and, in some cases, harvesting plants on a contaminated site as a remediation method is an aesthetically pleasing, solar-energy driven, passive technique that can be used along with, or in some cases, in place of mechanical cleanup methods.

Phytoremediation can be used to clean up metals, pesticides, solvents, explosives, crude oil, polyaromatic hydrocarbons, and landfill leachates.

How does phytoremediation work?

Phytoremediation (the term *phyto*- means *plant*) is a general term for several ways in which plants are used to clean up, or *remediate*, sites by removing pollutants from soil and water. Plants can break down, or *degrade*, organic pollutants or stabilize metal contaminants by acting as filters or traps. Some of the methods that are being tested are described in this fact sheet.

Metals Remediation

At sites contaminated with metals, plants are used to either stabilize or remove the metals from the soil and ground water through two mechanisms: *phytoextraction* and *rhizofiltration.*

Phytoextraction, also called phytoaccumulation, refers to the uptake of metal contaminants by plant roots into plant stems and leaves (Figure 1). Certain plants absorb unusually large amounts of metals in comparison to other plants. One or a combination of these plants is selected and planted at a particular site based on the type of metals present and other site conditions. After the plants have been allowed to grow for some time, they are harvested and either incinerated or composted to recycle the metals. This procedure can be repeated as many times as necessary to bring contaminant levels in the soil down to allowable limits. If plants are incinerated, their ash must be disposed of in a hazardous waste landfill, but the volume of ash will only be about 10% of the volume that would be created if the contaminated soil itself were dug up for treatment.

Metals such as nickel, zinc, and copper are the best candidates for removal by phytoextraction because they happen to be the favorites of the approximately 400 known plants that absorb unusually large amounts of metals. Plants that absorb lead and chromium are being studied and tested.

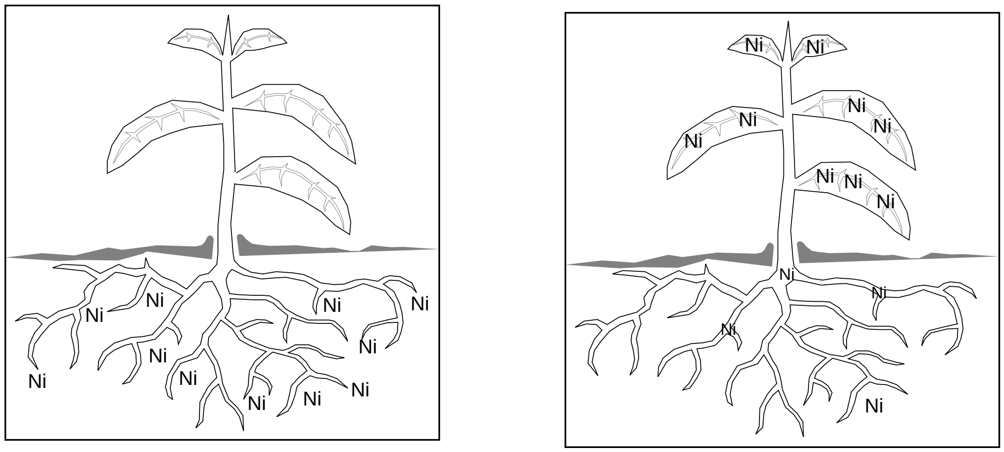
Rhizofiltration (*rhizo*- means *root*) has shown promise for dealing with metals contamination in water. Rhizofiltration is similar to phytoextraction, but the plants to be used for cleanup are raised in greenhouses with their roots in water rather than in soil. When the plants have developed a large root system, contaminated water is collected from a waste site and

A Quick Look at Phytoremediation

- Is an aesthetically-pleasing, passive, solar-energy driven cleanup technique.
- Is most useful at sites with shallow, low levels of contamination.
- Is useful for treating a wide variety of environmental contaminants.

Printed on Recycled Paper

Figure 1. Uptake of Metals (Nickel) by Phytoextraction



Nickel is removed from soil by moving up into plant roots, stems, and leaves. The plant is then harvested and disposed of and the site replanted until the nickel in the soil is lowered to acceptable levels.

brought to the plants where it is substituted for their water source. The roots take up the water and the contaminants along with it. As the roots become saturated with contaminants, they are harvested and disposed of. In addition to being useful for removing metals from water, rhizofiltration may prove useful for industrial discharge, agricultural runoff, acid mine drainage, and radioactive contamination. For example, sunflowers were used successfully to remove radioactive contaminants from pond water in a test at Chernobyl, Ukraine.

Treating Organic Contaminants

Organic contaminants (those that contain carbon and hydrogen atoms) are common environmental pollutants. There are several ways plants can be used for the phytoremediation of these contaminants: *phytodegradation, enhanced rhizosphere biodegradation, organic pumps,* and *phytovolatilization.*

What Is An Innovative Treatment Technology?

Treatment technologies are processes applied to the treatment of hazardous waste or contaminated materials to permanently alter their condition through chemical, biological, or physical means. *Innovative treatment technologies* are those that have been tested, selected or used for treatment of hazardous waste or contaminated materials but lack well-documented cost and performance data under a variety of operating conditions.

Phytodegradation is a process in which plants are able to *degrade* (break down) organic pollutants. In some cases, the pollutants degraded into simpler molecules are used to help the plant grow faster (Figure 2). Plants contain *enzymes*, a broad category of chemical substances that cause rapid chemical reactions to occur. Some enzymes break down and convert ammunition wastes, others degrade chlorinated solvents such as trichloroethylene (TCE), and others degrade herbicides.

Enhanced rhizosphere biodegradation takes place in the soil surrounding the plant roots (the *rhizosphere*) and is a much slower process than phytodegradation. Microorganisms (yeast, fungi, or bacteria) consume and digest organic substances for nutrition and energy. Certain microorganisms can digest organic substances such as fuels or solvents that are hazardous to humans and break them down into harmless products in a process called *biodegradation.* Natural substances released by the plant roots—sugars, alcohols, and acids—contain organic carbon that provides food for soil microorganisms and the additional nutrients *enhance* their activity. Biodegradation is also aided by the way plants loosen the soil and transport water to the area. The fact sheet entitled *A Citizen's Guide to Bioremediation* describes the biodegradation process in detail (see page 4).

Trees can act as **organic pumps** when their roots reach down toward the water table and establish a dense root mass that takes up large quantities of water. Poplar trees, for example, pull out of the ground 30 gallons of water per day, and cottonwoods can absorb up to 350 gallons per day. The pulling action caused by the roots decreases the tendency of surface pollutants to move downward towards ground water and into drinking water. Poplars planted along stream beds in agricultural areas reduce the amount of excess fertilizer and herbicides that get into the streams and ground water. In another similar application, trees planted on top of landfills as organic substitutes for the traditional clay or plastic caps, suck up rainwater that could otherwise seep through the landfill and come out the bottom as contaminated “leachate.”

Phytovolatilization occurs as growing trees and other plants take up water and the organic contaminants in it. Some of these contaminants can pass through the plants to the leaves and evaporate, or *volatilize,* into the atmosphere. Poplar trees, for example, volatilize 90% of the TCE they suck up.

Does phytoremediation work at every site?

Phytoremediation can be used to clean up metals, pesticides, solvents, explosives, crude oil, polyaromatic hydrocarbons, and landfill leachates. Phytoremediation is used in combination with other cleanup approaches as a “finishing” step. Although phytoremediation is significantly slower than mechanical methods, and is limited to the depth that the roots can reach, it can clean out the last remains of contaminants trapped in the soil that mechanical treatment techniques sometimes leave behind.

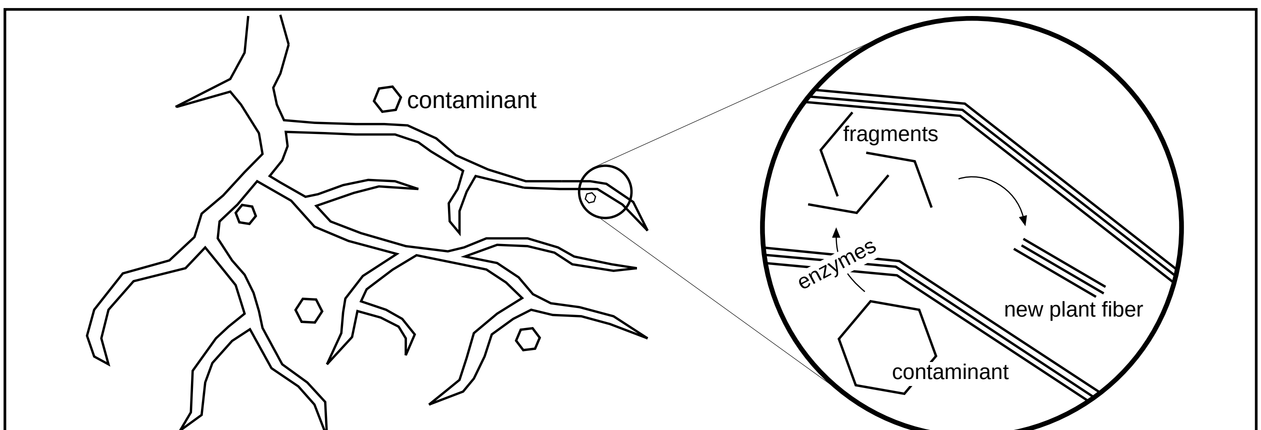
Generally, the use of phytoremediation is limited to sites with lower contaminant concentrations and contamination in shallow soils, streams, and ground water. However, researchers are finding that the use of trees (rather than smaller plants) allows them to treat deeper contamination because tree roots penetrate more deeply into the ground. Contaminated ground water very deep underground may be treated by pumping the water out of the ground and using it to irrigate plantations of trees.

Further research is needed to study the effects on the food chain that could occur if insects and small rodents eat the plants that are collecting metals and are then eaten by larger mammals. Also, scientists still need to establish whether contaminants can collect in the leaves and wood of trees used for phytoremediation and be released when the leaves fall in the autumn or when firewood or mulch from the trees is used.

Where has it been used?

Phytoremediation has been successfully tested in many locations. In Iowa, poplar trees planted along a stream bank between a corn field and the stream acted as natural pumps to keep toxic herbicides, pesticides, and fertilizers out of the streams and ground water. When the trees were three years old, researchers tested the levels of the nitrate contamination in the ground water at the edge of the cornfield and found it to be 150 milligrams per liter (mg/L). The ground water among the poplar trees along the stream bank, however, had nitrate concentration of only 3 mg/L—well under the EPA nitrate limit of 45 mg/L in drinking water. The table on page 4 lists some phytoremediation projects.

Figure 2. Destruction of Organic Contaminants by Phytodegradation



Enzymes in plant roots break down (degrade) organic contaminants. The fragments are incorporated into new plant material.

Table 1. Examples of Sites Testing Phytoremediation*

Location	Application	Contaminants	Medium	Plant
Ogden, UT	Phytoextraction	Petroleum hydro-carbons	Soil Ground water	Alfalfa, Poplar Juniper, Fescue
Portsmouth, VA	Rhizofiltration Phytodegradation	Petroleum	Soil	Grasses Clover
Milan, TN	Phytodegradation	Explosives wastes	Sediment	Duckweed Parrot feather
Aberdeen, MD	Organic Pumps Phytovolatilization Rhizofiltration	Trichloroethylene Trichloroethane	Ground Water	Poplar trees

** Not all waste types and site conditions are comparable. Each site must be individually investigated and tested. Engineering and scientific judgment must be used to determine if a technology is appropriate for a site.*

For More Information

The publications listed below can be ordered free of charge by faxing your request to NCEPI at 513-489-8695. If NCEPI is out of stock of a document, you may be directed to other sources. If you choose, you may write to NCEPI at:

National Center for Environmental Publications and Information (NCEPI)
P.O. Box 42419
Cincinnati, OH 45242

- "Tree Buffers Protect Shallow Ground Water at Contaminated Sites," *Ground Water Currents* (newsletter), December 1993, EPA 542-N-93-011.
- Recent Developments for *In Situ* Treatment of Metal Contaminated Soils, (Available Fall 1996), EPA 542-R-96-008.
- *A Citizen's Guide to Bioremediation,* April 1996, EPA 542-F-96-007.
- *Soil Stabilization Action Team,* April 1996, EPA 542-F-96-010d.
- "Mother Nature's Pump and Treat," by Kalle Matso in *Civil Engineering,* October 1995, pages 46-49.
- "The Green Clean," by Kathryn Brown Sargeant in *BioScience,* October 1995, pages 579-582.